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Effects of eco-driving instructions using a vehicle with automatic transmission on urban roads

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Abstract: Eco-driving instructions could reduce fuel consumption to up to 20% (EcoMove, 2010). Participants (N=13) drove an instrumented vehicle (i.e. Toyota Camry 2007) with an automatic transmission. Fuel consumption of the participants were compared before and after they received eco-driving instructions. Participants drove the same vehicle on the same urban route under similar traffic conditions. Results show that, on free flow sections of the track, all participants drove slightly faster (on average, 0.7 Km/h faster), during the lap for which they were instructed to drive in an eco-friendly manner as compared to when they were not given the eco-driving instruction. Suprisingly, eco-driving instructions increased the RPM significantly in most cases. Fuel consumption slightly decreased (6%) after the eco-driving instructions. We have found strong evidence showing that the fuel saving observed in our experiment (urban environment, automatic transmission) fall short of the 20% reduction claimed in other international trials.

Keywords: Eco-driving, urban roads, driving performance.

Introduction

Transport accounts for nearly 27% of total CO_2 emissions from fossil fuel combustion. Transport is the second largest CO_2 - emitting sector after electricity production (ITF, 2010). Many countries have promoted eco-driving as a key element of national strategies to reduce fuel consumption and CO_2 emissions. Eco-driving consists of a variety of driving techniques (style) that save fuel and lower emissions. Eco-driving instructions vary considerably per country. Apart from Sweden, which has introduced a new law in 2007 to test eco-driving skill during a practical vehicle test, there is no international standard or benchmark on the optimal method to instruct and perform eco-driving. Eco-driving generally attempts to change drivers' behavior through instructions such as driving more smoothly by anticipating changes in the traffic, shifting gear sooner, operating the vehicle within an optimum rev range, avoiding jerky braking/acceleration and avoiding traffic jams.

European Union regulations already require eco-driving to be taught to novice drivers. Japan achieved its 2010 goal of reducing CO_2 emissions by 31 million tons below 2001 levels by encouraging drivers to use their vehicles more efficiently through eco-driving (ITF, 2010). Traffic intensity has increased in urban transport systems and driving pattern over a specified route varies to a great extent (Saboohi and Farzaneh, 2009). In order to effectively reduce CO_2 emissions it is necessary to change driver behavior or style in a way such that eco-driving becomes the norm rather than the exception (Barkenbus, 2010).

The claimed advantages of the eco-driving approach are that they can apply to vehicles of any age or size, they can take effect across the entire fleet of vehicles immediately at low cost (as opposed to being phased in), and that they can result in immediate savings to individuals from greater fuel efficiency, better safety and perhaps lower insurance rates (Barkenbus, 2010).

One of the most popular eco-driving instruction for drivers operating vehicles with a manual gear box is to shift to the highest gear as soon as possible without lugging the engine. Such instructions reduce engine revolutions per minute (RPM) and consequently the fuel consumption. However, most passenger vehicles in Australia are equipped with an automatic transmission, also called automatic gear box. Drivers of automatic transmission vehicles are not aware of the gear they are driving in (e.g. 1,2,3,4,5) nor are they able to control gear shifts. Furthermore, it is widely accepted that the fuel consumption for passenger vehicles is optimal around 80km/h. However most cities or urban roads in Australia have a posted speed limit of 60 km/h or less.

Japan has conducted many trials to evaluate the effect of eco-driving instructions on fuel consumption in urban road and automatic vehicles (Shinpo, 2007). The Smart Drive study has established that almost 50% of fuel consumption in urban environments is spent on accelerating and decelerating, as illustrated in Figure 1 (Smart Drive, 2006). Various Japanese eco-driving interventions have shown fuel savings of up to 20%.

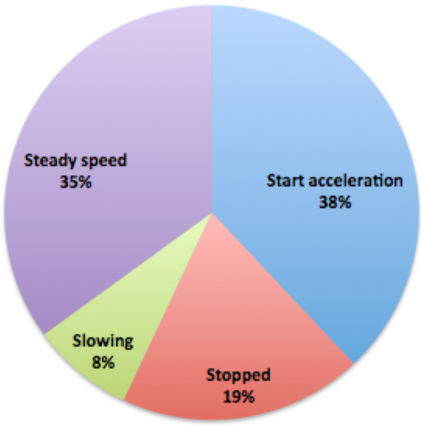

Figure 1: Fuel consumption pattern (adapted from Smart Drive, 2006)

In France, St Pierre et al (2010) conducted a study which comprehensively characterised the immediate effects of eco-driving instructions on driver behaviour in a vehicle with manual transmission on semi-rural roads. Our study builds upon their fundings and focusses on the effects of eco-driving instructions on driver's steady speed, acceleration and deceleration, in a vehicle with an automatic transmission and on urban roads. Our experiment will test the following two hypotheses:

- Driving an automatic passenger vehicle can hamper eco-driving performance as drivers cannot be aware of the gear number nor shift it.
- Eco-driving instructions do not have positive effects in an urban environment as vehicles do not have steady speed and cannot reach the optimal speed (80km/h).

This pilot study comprises a within subject comparison of driving performance with and without eco-driving instructions using a medium size instrumented passenger vehicle featuring an automatic gear box travelling in an urban environment.

Method

Experimental Design

<u>Instrumented Vehicle (Figure 2)</u>

A medium size Toyota Camry Altise (2007) with automatic gear box was fitted with

- IBEO Laser scanner for leading vehicle detection.
- Vigil system (GPS receiver, accelerometer and cameras) for vehicle position, vehicle dynamics and to record the images of the road ahead and images inside the vehicle.
- NeoOBD On-board Diagnostic Device (OBDII) for retrieving vehicle's RPM, speed, instantaneous fuel consumption and the percentage of throttle open.

Figure 2: Instrumented Toyota Camry vehicle with IBEO laser, GPS, OBDII reader, accelerometer (Vigil) and video cameras

All the above mentioned sensory data were recorded in a system using RTMaps software (www.intempora.com). The architecture of the in-vehicle system is illustrated in Figure 3.

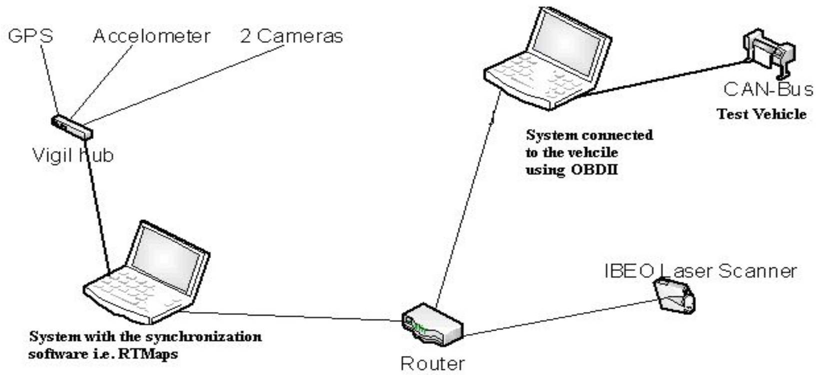

Figure 3: In-vehicle infrastructure for data collection

<u>Test track specification</u>

The driving experiment was conducted in an urban environment at Kelvin Grove, Brisbane, Australia. The test track features a small portion of 2 lane motorway (3 km) and suburban single lane roads (2 km). Driving such a small distance allows us to control for driver's fatigue and habituation. Figure 4 illustrates the test track used for the experiment. Figure 4 (b) is a GPS point tracking of one of the participants. This image is also used to highlight the track's length. The track's length will be used to explain the start/stop of the different road types (i.e. motorway, incline etc) in the Procedure section. The map (GoogleMap) of the track is presented in Figure 4 (a). Specifications for the test track/circuit are given below

- A fixed start point and end point from where the test vehicle starts and stops respectively.
- Clearly visible marked lanes (two lanes). The length of the track was approximately 5000 meters for encompassing different classifications of the road (motorway, suburbs, incline road etc)

Traffic conditions

The experiment was designed for an urban environment without heavy traffic in which reaching the optimal speed of 80km/h for fuel consumption was unlikely. The time and location of the experiment were chosen to maximise free flow opportunities in most of the route. Any event where the driver has to stop or slow down due to traffic light or hazards were excluded from the analysis.

Participant Recruitment

Participants were recruited via word of mouth within the Queensland University of Technology. In order to be eligible, participants were required to have a driver's licence issued within Australia, be aged between 18 and 60, have no medical conditions that affect their driving, be familiar with an automatic transmission, have driven a medium passenger car similar to the test vehicle and be an experienced driver (more than 5 years driving licence).

Procedure

Upon their arrival, each driver was briefed about the itinerary, track geometry and the driving manoeuvres they would have to perform. Participants drove on a 5 km circuit around Kelvin Grove, which encompassed different road types (motorway, suburban roads) and significant variations in elevation. The suburban roads feature traffic lights and stop signs. Each participant drove three laps of the circuit, with a total duration of approximately 30 minutes per session. A research officer sat on the back seat to operate the equipments and to assist the participants if questions were asked. The first lap was a familiarisation drive. The second and third laps were randomly driven with or without any eco-driving instructions. The eco-driving instructions were given just before the corresponding lap. The instructions were the following:

- Slow down and watch speed
- Accelerate and brake smoothly
- Anticipate the road ahead and avoid unnecessary abrupt braking

- Choose the appropriate speed

Each participant's driving task was divided into three road sections corresponding to the road characteristic (i.e. motorway, incline and suburban). Every lap started and stopped at the positions identified as 'A' and 'C' in Figure 4. Each participant started from point 'A' as shown in Figure 4 and completed the lap (anticlockwise) in which the motorway section (speed limit 80km/h) started 800 meters from the starting point A. The motorway ended at 2200 meters from the starting point. The section of road between 2500 meters and 3500 meters, from A, was a moderately inclined road (speed limit 60km/h). The ascending angle of inclination was measured to be 4 degrees. The rest of the roads were classified as suburban roads.

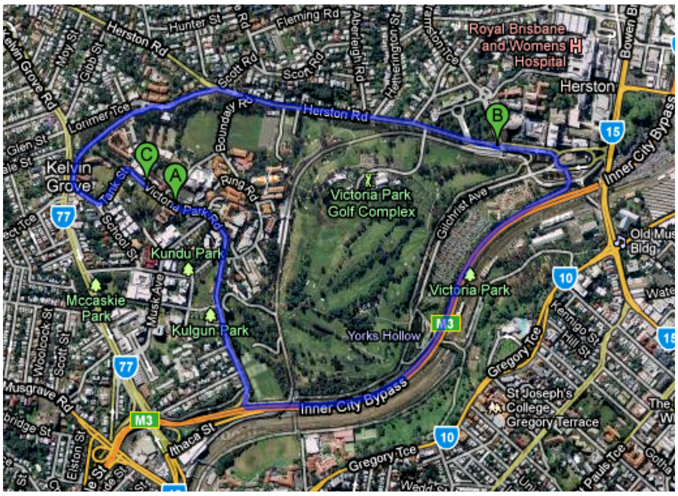

Figure 4 (a): Test Track (GoogleMap)

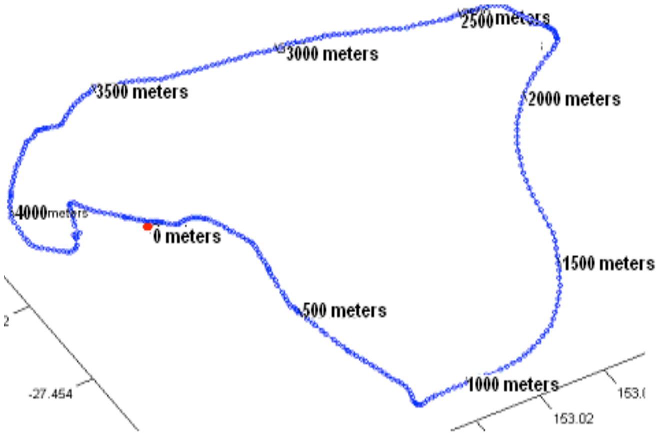

Figure 4 (b): The selected track's length in meters to identify the start/stop of different road segments

Data collection

The data related to the vehicle dynamics and obstacle positioning was recorded with the in-vehicle technology described in Figure 3. Data was collected from the sensors of the instrumented vehicle and the surrounding environment at varying frequencies. Data from the GPS was retrieved at 1Hz, vehicle dynamics (i.e. RPM, speed, throttle position) at >50Hz, cameras at 30Hz and laser scanner at 50Hz.

The information available from the CAN-bus differs for manufacturers and models. As this CAN-bus information is not publicly available, different signals were analyzed and tested using a case by case approach. The parameters that were successfully analyzed from CAN-bus included RPM, speed, the percentage of throttle open and the mass air flow rate.

We calculated the instatenous fuel consumption using speed and air flow (throttle position) from CAN-BUS readout. Lee et al. (2011) demonstrated positive relationships between engine RPM, throttle position, and actual fuel consumption. The formulae for miles per gallon (MPG) we have used is as follows (from Circuit Cellar).

MPG = (14.7 * 6.17 * 4.54 * VSS * 0.621371) / (3600 * MAF / 100)

where *14.7 = grams of air to 1 gram of gasoline(ideal air/fuel ratio); 6.17 = pounds per gallon density of gasoline; 4.54 = grams per pound (conversion);VSS = vehicle speed in kilometers per hour; 0.621371 = miles per hour/kilometers per hour (conversion); 3600 = seconds per hour (conversion); MAF = mass air flow rate in 100 grams per second; 100 = c MAF in grams per second (conversion).*

A benchmark fuel economy was used in order to calculate the percentage increase or decrease in the fuel consumption for the participants. New EU regulations introduced to reduce the average emissions of cars sold from 2012, require gasoline fuel (petrol) cars to have fuel economy of 50 miles per gallon (Climate Action, 2011). Therefore, fuel economy of 21 Km per liter (i.e. 50 MPG) was considered as the benchmark for this study.

Data Analysis

The characteristics of driving performance such as speed, RPM, throttle, fuel consumption with and without eco-driving instructions where compared within participants using paired T-test using R statistical software. We extracted and analysed the speed when there is no vehicle 30 meters in front of the test vehicle (free flow). The detection of vehicles in front was made with the IBEO laser scanner and confirmed manually by visualisation of the front camera footages.

Results

Participants were 13 licenced car drivers, 9 males and 4 females, aged between 25 and 60 years. RTMaps was able to successfully record, synchronize and replay data from the sensors illustrated in Figure 3. The average following distance clearance, as measured by the IBEO laser device during the experiment was approximatevely 28 meters. Therefore participants were generally able to drive in free flow traffic. IBEO data and camera footage were used to remove the portion of the recordings where a participant was slowed down by another vehicle or stopped because of traffic light or pedestrians crossing. All participants complied to the posted speed limit.

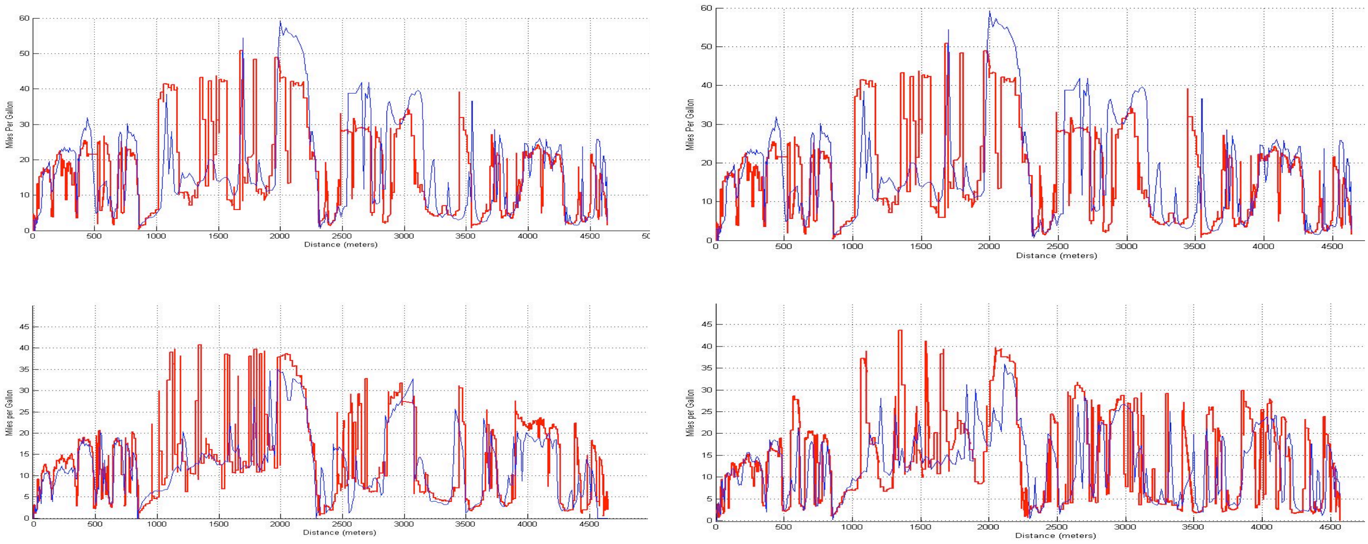

Figure 5: Example of fuel consumption record for a few participants

The fuel consumption variation (pattern) with or without eco-driving instruction were similar within participants. For example, Figure 5 illustrates the fuel consumption pattern for a few participants. Red line corresponds to the consumption with eco-driving instructions while the blue line represents consumption without eco-driving instructions. Red and blue lines follow the same pattern for the same location.

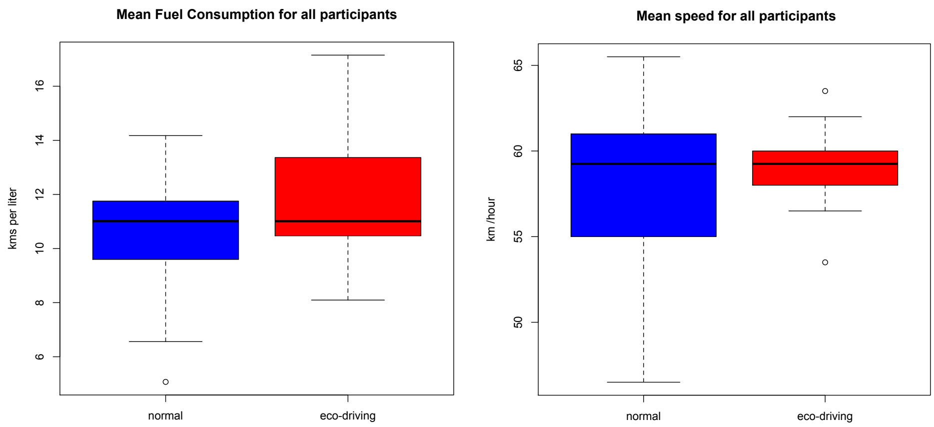

Figure 6: Mean speed and Instantaneous Fuel consumption for all participants

The average instantaneous fuel consumption for all participants was higher (+1.4 km per litre) without eco-driving instruction (normal) as shown in Figure 6. Higher fuel consumption resulted in less distance traveled per litre of fuel. However, the difference was not statistically significant (p = 0.063). The average speeds for the participants before and after the eco-instructions were 58.3Km/h and 59 Km/h respectively and not statistically significant (p = 0.6543). However, the average RPM was significantly higher after eco-driving instruction (p = 0.01) as illustrated in Figure 7.

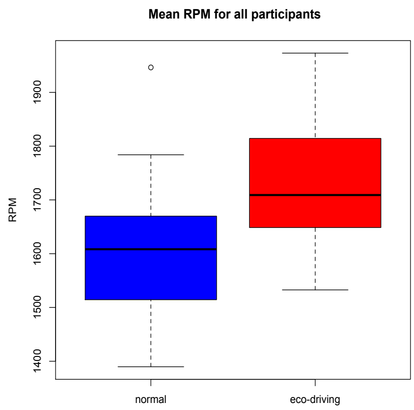

Figure 7: Average RPM for the entire track for all participants

Further analysis was performed by distinguishing different road types. The mean speed before and after the eco-instructions on the incline (4 degree) and on the motorway were very similar, as illustrated in Figure 8. The fuel consumption on motorway and road with 4 degree incline, illustrated in Figure 9, shows that during the driving with eco-instructions on the incline section, the participants had an average increase of 7.5 percent (with respect to benchmark 21Km/L) in their distance traveled per litre.

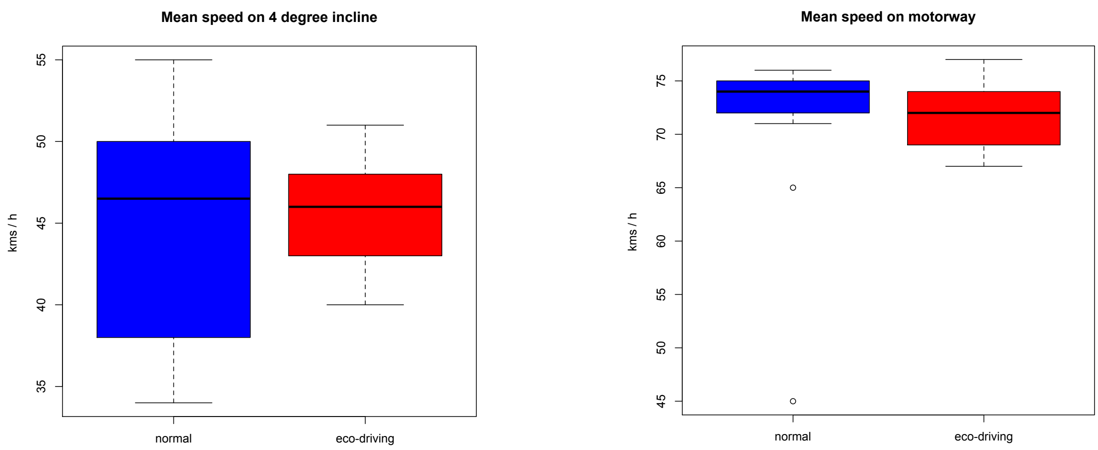

Figure 8: Average speed on for 4 degree incline section and motorway

However this difference was not statistically significant (p = 0.19). The consumption on motorway is relatively more significant compared to the incline. After receiving eco-driving instruction, participants traveled an average of 1.6 Km more per litre on motorway (p = 0.06). During driving with eco-instructions on the motorway section, the participants on average showed an increase of 5.8 percent (w.r.t benchmark 21Km/L) in their distance traveled per litre.

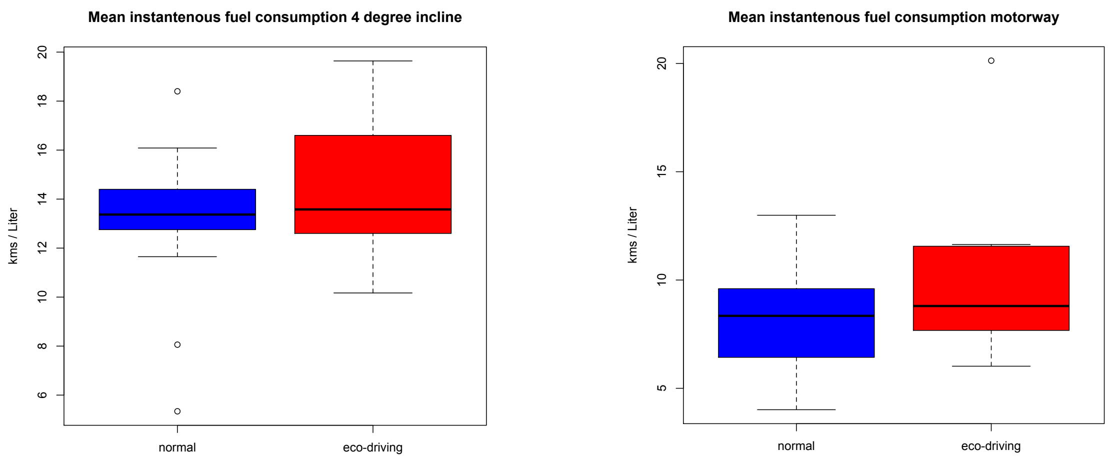

Figure 9: Average consumption for 4 degree incline section and motorway

The relatively modest decrease in fuel consumption after eco-driving instructions could be attributed to the fact that some drivers drove with higher RPM but at almost the same speed. At lower speeds the vehicle shifts to a lower gear in an automatic gear box. Driving at lower gears could increase the fuel consumption. Unfortunately ,we were not able to retrieve the gear level from the OBDII.

Limitations

As a pilot study, this experiment has several limitations. Firstly, we had a small sample size (N = 13) and sample type which might have impacts on its statistical validity. Also, the psychological profile of the drivers were not controlled for (e.g. sensation seekers).

Despite these limitations this pilot studyshowed statistically significant change in the RPM variable when participants received eco-driving instructions. This study can be conducted with more participants to confirm the results for the variables that did show change, but for which, the change was not statistically significant.

Conclusions

Both hypotheses described in the introduction were proven wrong. We have shown that eco-driving instructions using a vehicle with an automatic gear box have positive impacts on driving behaviour in urban roads, but not as much as the expected 20% (EcoMove, 2010). The eco-driving instructions resulted in reduced fuel consumption on urban roads. Even though the fuel consumption for all participants on average decreased by 6% during the eco-driving lap, some drivers achieved major improvements, of up to 14%. The significant increase of RPM during eco-driving might have offset the theoretical fuel consumption gain. Fuel consumption is related to the RPM which is, in turn, influenced by the speed and gear level. Drivers of automatic vehicles cannnot control gear shift which prevents them from fully benefiting from complying to eco-driving instructions.

Future work will include detailed analyses of the environmental effects, to check whether the statistically significant increase in engine RPM in eco-driving mode might have been a consequence of driving in lower gears. This analysis will also examine the effects of the eco-driving instructions (technology or education Rouzikah *et al.* 2012) on safety indices (e.g. following distances).

Our analysis on the impacts of different urban road types and time of day on eco-driving behaviour will assist in designing comprehensive eco-driving strategies for urban contexts. These eco-driving strategies will have the ability to adapt to the changing environmental scenarios.

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